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(54) Title: METHOD AND APPARATUS FOR PROVIDING HIGH SPEED SERVICES USING A WIRELESS COMMUNICATIONS SYSTEM

(57) Abstract

A method and apparatus for scheduling transmissions between a plurality of communications sites within a communications system. The communications system provides service to a service area which is divided into sectors. Each sector is assigned at time subframe in a pattern where adjacent sectors use different subframes. Communications sites within each sector communicate packets of information in at least one time subframe according to a schedule to minimize interference from other communications sites.

METHOD AND APPARATUS FOR PROVIDING HIGH SPEED SERVICES
USING A WIRELESS COMMUNICATIONS SYSTEM

BACKGROUND OF THE INVENTION

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The invention relates generally to wireless
communications systems. More particularly, the
invention relates to providing high-speed broadband
services to a large number of users by utilizing a
10   minimum amount of bandwidth in a wireless communications
system.

The need for high-speed broadband packet services
will grow tremendously in the coming years as
work-at-home, telecommuting and Internet access become
15   increasingly popular. Customers are expecting high
quality, reliability and easy access to high-speed
communications from homes and small businesses. Data
rates of at least 10 mega-bits per second (Mbps) are
needed to provide high speed services for: a) accessing
20   the World Wide Web (WWW) for information and
entertainment, b) providing data rates comparable to
local-area networks (LAN) for telecommuters to access
their computer equipment and data at the office, and c)
multimedia services such as voice, image and video.
25   Traditional wireless communications systems have a
problem delivering high-speed services because of the
amount of bandwidth these services require. Bandwidth
is a key limiting factor in determining the amount of

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information a system can transmit to a user at any one
time. In terms of wireless networks, bandwidth refers
to the difference between the two limiting frequencies
of a band expressed in Hertz (Hz).

5   The concept of bandwidth may be better understood
using an analogy. If information carried by a network
were water, and links between communication sites were
pipes, the amount of water (i.e., information) a network
could transmit from one site to another site would be

10   limited by the speed of the water and the diameter of
the pipes carrying the water. Ignoring speed for a
moment, the larger the diameter of the pipe, the more
water (i.e., information) can be transmitted from one
site to another in a given time interval. Likewise, the

15   more bandwidth a communications system has available to
it, the more information it can carry.
        Traditional wired communications systems using
modems and a physical transmission medium such as
twisted pair copper wire, cannot currently achieve the

20   data rates necessary to deliver high-speed service due
to bandwidth limitations (i.e., small pipes). In an
attempt to solve this bandwidth problem, the local
exchange companies (LEC) have been engaged in planning
and deploying hybrid fiber/co-ax (HFC) and switched

25   digital video (SDV) networks. These wired-network
approaches to providing high-speed access, however,
require a substantial market penetration to keep the
per-subscriber costs at an acceptable level due to the
high costs involved.

30   Similarly, traditional wireless systems such as
narrowband cellular and Personal Communications Services
(PCS) are bandwidth limited as well. As an alternative,
wireless solutions such as Multichannel Multipoint
Distribution Service (MMDS) and Local Multichannel

35   Distribution Service (LMDS) have become attractive for
low take-rate scenarios, e.g., a market penetration of a

few percent. The benefits of wireless systems for
delivering high-speed services is that they can be
deployed rapidly without installation of local wired
distribution networks. The problem with MMDS and LMDS,
5   however, is that these solutions presently offer limited
uplink channel capacity. Moreover, these solutions may
not be capable of supporting a large number of users due
to limited frequency reuse.

One solution for solving the bandwidth limitation
10   problem for wireless systems is to maximize the
available bandwidth through frequency reuse. Frequency
reuse refers to reusing a common frequency band in
different cells within the system. The concept of
frequency reuse will be discussed in more detail with
15   reference to FIGS. 1 and 2.

FIG. 1 is a diagram of a typical wireless
communication system. A typical wireless communications
system includes a plurality of communications sites,
such as mobile telephone switching office (MTSO), base
20   stations, terminal stations, or any other site equipped
with a radio transmitter and/or receiver.

FIG. 1 shows a base station 20 in communication
with terminal stations 22. Base station 20 is usually
connected to a fixed network, such as the PSTN or the
25   Internet. Base station 20 could also be connected to
other base stations, or connected to a MTSO in the case
of mobile systems. Terminal stations 22 can be either
fixed or mobile.

Base station 20 communicates information to
30   terminal stations 22 using radio signals transmitted
over a range of carrier frequencies. Frequencies
represent a finite natural resource, and are in
extremely high demand. Moreover, frequencies are
heavily regulated by both Federal and State governments.
35   Consequently, each cellular system has access to a very
limited number of frequencies. Accordingly, wireless

systems attempt to reuse frequencies in as many cells
within the system as possible.

To accomplish this, a cellular system uses a
frequency reuse pattern. A major factor in designing a
5   frequency reuse pattern is the attempt to maximize
system capacity while maintaining an acceptable signal-
to-interference ratio (SIR). SIR refers to the ratio of
the level of the received desired signal to the level of
the received undesired signal. Co-channel interference
10   is interference due to the common use of the same
frequency band by two different cells.

To determine frequency reuse, a cellular system
takes the total frequency spectrum allotted to the
system and divides it into K frequency reuse patterns.
15   FIGS. 2(A) through 2(D) illustrates examples of
frequency reuse patterns of K = 4, 7, 12 and 19.

As shown in FIGS. 2(A) through 2(D), a cellular
communications system has a number of communications
sites located throughout a geographic coverage area
20   serviced by the system. This geographic area is
organized into cells and/or sectors, with each cell
typically containing a plurality of communications sites
such as a base station and terminal stations. A cell is
represented in FIGS. 2(A) through 2(D) as a hexagon.
25   FIG. 2(A) shows a frequency reuse pattern where K = 4.
Cells are grouped into sets of four, with each set
employing frequency bands 1 through 4. This group of
four cells is then repeated until the entire service
area is covered. This same pattern is shown in FIGS.
30   2(B), 2(C) and 2(D) for sets of 7, 12 and 19 cells,
respectively. Thus, in essence, the frequency reuse
pattern represents how much geographic distance must be
maintained between cells that use common frequency bands
such that the co-channel interference for these cells is
35   kept below a given threshold to ensure successful signal
reception.

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        The most aggressive frequency reuse pattern for
cellular systems is where K = 1. Under this pattern,
the same frequency band can be reused in every cell in
the cellular communications system. In typical

5   narrowband cellular systems, the total amount of
frequency spectrum available to a system is divided by
K. This determines how much frequency is available for
a particular cell. For example, if a cellular system is
allocated 20 megahertz (MHZ) of spectrum, and the

10   frequency reuse pattern is K = 4, then each cell has 5
MHZ worth of frequency on which to transmit radio
signals. If K = 1, the entire 20 MHZ worth of frequency
spectrum is available to every cell to potentially
transmit information.

15   To better understand the magnitude of benefit given
by a frequency reuse pattern of K = 1 discussed in the
above example, the figures for a real communications
system will be used. The frequency assignment for U.S.
mobile cellular systems is 824-849 MHZ and 869-894 MHZ

20   for a given service area. Since each service area is
served by two cellular network operators, each cellular
system must split the available bandwidth for the given
service area. This amounts to a total of 25 MHZ of
available bandwidth per system, with 12.5 MHZ being used

25   for transmitting from a base station to a terminal
station (referred to as the downlink), and 12.5 MHZ
being used for transmitting from the terminal station to
the base station (referred to as the uplink). A typical
U.S. mobile cellular system has a frequency reuse

30   pattern of K = 21. Thus, each cell has roughly only 1.2
MHZ (25 MHZ divided by 21) of spectrum to transmit
information. If a frequency reuse pattern of K = 1
could be established, the entire 25 MHZ is available for
transmitting information for each cell. This results in

35   a twenty-one fold increase in available frequency
spectrum for each cell. Using the analogy again, the

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diameter of the pipe is increased twenty-one times.

　　　Several existing systems currently employ frequency
reuse patterns of K = 1. One example includes cellular
systems employing code division multiple access (CDMA).

5　CDMA systems spread the transmitted signal across a wide
frequency band using a code. The same code is used to
recover the transmitted signal by the CDMA receiver.
CDMA systems reuse the same frequencies from cell to
cell. CDMA systems, however, require a large amount of

10　frequency spectrum. Moreover, the amount of spectrum
required by CDMA systems to offer high-speed broadband
services to a large number of users is commercially
unrealistic.

　　　Another example for aggressive frequency reuse

15　includes cellular systems employing time division
multiple access (TDMA), an example of which is discussed
in United States Patent Number 5,355,367. The system
discussed in U.S.P.N. 5,355,367 is a TDMA system using
the redundant transmission of information packets to

20　ensure an adequate SIR for a call. The use of redundant
packet transmissions, however, merely trades one
inefficiency for another. Although a frequency band can
be reused from cell to cell, redundant packet
transmission means that a smaller portion of that

25　frequency band is now available for use by each cell in
the system since multiple packets are required to ensure
the successful reception of a single packet.

　　　In addition to the frequency reuse problem,
traditional cellular systems are not engineered to allow

30　a communications site to use the entire bandwidth
available to the system ("total system bandwidth"), due
to the low data rate expected by customers. Rather,
traditional cellular systems employ various techniques
in both the frequency domain and time domain to maximize

35　the amount of users capable of being serviced by the
system. These techniques are predicated on allocating

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smaller portions of the total system bandwidth to
service individual communication sites. These smaller
portions are incapable of providing sufficient bandwidth
to offer high speed services.

5   An example of a technique employed in the frequency
domain is Frequency Division Multiple Access (FDMA).
FDMA splits the available bandwidth into smaller
sections of bandwidth under the concept of providing
less bandwidth for a greater number of users. Using the
10   analogy, a single large pipe is separated into a number
of smaller pipes, each of which is assigned to a sector
or cell. Unfortunately, the trade-off is that these
smaller frequency bands are not large enough to support
high-speed broadband packet services. Moreover, by
15   definition, a communication site is not capable of using
the total system bandwidth, but rather is limited to a
discrete portion of the total system bandwidth.
       An example of a technique employed in the time
domain is TDMA. TDMA divides the available bandwidth
20   into discrete sections of time, and allocates each
section of time (typically referred to as a time slot)
to each communication site. Each communication site
transmits and receives information only at the site's
specific time slot, thereby preventing collisions
25   between communication sites. Using the analogy, each
cell or sector has access to the entire pipe for a fixed
amount of time. Traditional TDMA systems, however, are
designed to handle circuit switching and, therefore, are
static in nature. These systems allocate a specific
30   time slot of a fixed duration for a specific
communication site for the entire length of a call. As
a result, a communication site cannot transmit more
information than can be accommodated by its assigned
time slot. In any event, these traditional TDMA systems
35   are not designed to take advantage of new switching
technology, such as packet switching.

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Some systems employ a combination of FDMA and TDMA to improve the call capacity of the system. These FDMA/TDMA systems, however, merely combine the disadvantages of both. Moreover, FDMA/TDMA systems do not permit a user access to the total system bandwidth on a dynamic basis.

To solve this problem, some TDMA systems employ a concept called "dynamic resource allocation" to share the radio resource among communications sites efficiently. Dynamic resource allocation methods, however, require a central controller or complicated algorithms to dynamically determine available time slots and coordinate their use.

In light of the foregoing, it can be appreciated that a substantial need exists for a system employing a frequency reuse pattern of K = 1 while allowing a communication site to utilize the total system bandwidth on a dynamic basis, thereby providing high-speed broadband packet services to a large number of users while minimizing the amount of required bandwidth.

SUMMARY OF THE INVENTION

This need and other needs are met using a method and apparatus for scheduling transmissions between a plurality of communications sites within a communications system. The communications system provides service to a service area which is divided into sectors. Each sector is assigned a time subframe in a pattern where adjacent sectors use different subframes. Communications sites within each sector communicate packets of information in at least one time subframe according to a schedule to minimize interference from other communications sites.

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BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a block diagram of a typical wireless system.

5 FIG. 2(A) shows a frequency reuse pattern when K = 4.

FIG. 2(B) shows a frequency reuse pattern when K = 7.

FIG. 2(C) shows a frequency reuse pattern when K = 10 12.

FIG. 2(D) shows a frequency reuse pattern when K = 19.

FIG. 3 is a cellular map with arrows indicating the major sources of interference for a downlink 15 transmission for a shaded sector within a cell.

FIG. 4 is a cellular map with arrows indicating the major sources of interference for an uplink transmission for a shaded sector within a cell.

FIG. 5 is a cellular map with each cell divided 20 into six sectors using two subframes in accordance with a first embodiment of the invention.

FIG. 6 is a diagram illustrating a left-right protocol in accordance with a second embodiment of the invention.

25 FIG. 7 is a cellular map with each cell divided into six sectors using six subframes in accordance with a third embodiment of the invention.

FIG. 8 is a diagram illustrating a staggered resource allocation protocol in accordance with a fourth 30 embodiment of the invention.

FIG. 9 is a normalized throughput v. normalized aggregated load graph in accordance with a fourth embodiment of the invention.

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DETAILED DESCRIPTION

In accordance with the present invention, a method
and apparatus are discussed for providing a frequency
5   reuse pattern of K = 1 for a wireless communications
system, while permitting each communication site within
a sector to utilize the entire bandwidth available to
the system on a dynamic basis. A cellular
communications system is one example of a system which
10   falls within the scope of the present invention.

Embodiments of the invention utilize a TDMA system
design so that each cell and sector of the system can
use a common frequency. The embodiments illustrated
herein identify the worst sources of interference for a
15   downlink and uplink transmission and reception between
communication sites within a cell. Through the use of
directional antennas, cell sectorization, and a
scheduling algorithm, these embodiments avoid the major
sources of interference for a communications site within
20   the system. This minimizes co-channel interference for
satisfactory radio signal reception to the point where
all available system bandwidth frequencies can be reused
from cell to cell, and by each communication site on a
dynamic basis.

25   In the context of this disclosure and the claims
appended hereto, any references to scheduling can be
implemented using a scheduler, and memory sufficient to
store the scheduling algorithm. A scheduler includes a
processing unit with sufficient processing speed.
30   Examples of processing units include a microprocessor
used in a general purpose computer or network server,
and also a special dedicated hardware device. Further,
any reference to communicating information includes
transmitting and/or receiving information.

35   To illustrate various embodiments of the invention,
assume a fixed (i.e., non-mobile) broadband

packet-switched TDMA wireless network with user data
rates of 10 Mbps, link lengths typically less than 10
kilometers and operating frequency in the range of 1 to
5 giga-hertz (GHz). To support a user data rate of 10
5   Mbps, the system utilizes a bandwidth of approximately
10 MHZ. It is worthy to note that although the various
embodiments are discussed in accordance with a fixed
network, a mobile network falls within the scope of the
invention as well.

10   The TDMA system is organized as follows. Each cell
is divided into multiple sectors, each of which is
covered by a directional antenna co-located with a base
station at the center of the cell. Terminal stations
also use directional antennas pointed to their

15   respective base station antennas. The beamwidth (angle)
of each base station antenna should be just wide enough
to cover the whole sector, while a terminal station
antenna pointing to a designated base station antenna
can have a smaller beamwidth to reduce interference.

20   The ratios of front-to-back-lobe gain ("FTB ratio") for
base station and terminal station antennas may be
different, and are assumed to be finite. Time is
slotted such that a packet of information can be
transmitted in each slot. In addition, the downlink and

25   uplink between terminal stations and base station can be
provided by time-division duplex (TDD) using the same
radio spectrum, or frequency-division duplex (FDD).

      More specifically, each cell is divided into six
sectors, each of which is served by a base station

30   antenna with 60 degree beamwidth. Terminal station
antennas can have an angle smaller than 60 degrees.
Even for this advantageous structure, optimal scheduling
of packet transmissions is complex, which is referred to
by mathematicians as an NP-complete problem. Therefore,

35   the various embodiments of the invention use a heuristic
approach to identify and avoid the major sources of

interference.

FIG. 3 is a cellular map with arrows indicating the major sources of interference for a downlink transmission for a shaded sector within a cell. Using a path loss model, the major interference for the downlink in the shaded sector is found to come from sectors in the same cell and sectors in other cells. Specifically, as shown in FIG. 3, alignment sector (A) and opposite sector (B) are the major sources of inter-cell interference. Sector (A) is a major source of inter-cell interference because a terminal station antenna in the shaded sector while pointing to its base station antenna also sees the front lobe of the base station antenna for Sector (A). Similarly, Sector (B) is another major source of inter-cell interference because of its close distance from the shaded sector.

FIG. 4 is a cellular map with arrows indicating the worst sources of interference for an uplink transmission for a shaded sector within a cell. Similar to the downlink map shown in FIG. 3, the source of major interference for the uplink is received from sectors in the same cell and other cells. For both the downlink and uplink, the interference is compensated for in part using directional antennas at the base station. Directional antennas limit interference received from neighboring cells because of the FTB ratio of the directional antennas and the distance between inter-cell interference sources and the receiving base station antenna located in the shaded sector.

FIG. 5 is a cellular map with each cell divided into six sectors and two time subframes (for a downlink or uplink transmission) in accordance with a first embodiment of the invention. The total amount of bandwidth available to the system is separated into a fixed number of time slots for a downlink or uplink. The time subframes shown in FIG. 5 are used to

illustrate either the uplink or downlink, but not both
simultaneously. The time slots used for a downlink or
uplink are grouped into subframes. Consecutive
subframes are labeled alternately by 1 and 2. Sectors

5 are also labeled by 1 and 2 such that no adjacent
sectors share the same label. Sectors with label i can
schedule packet transmission in time slots of subframe
i. As a result, each sector can transmit on a 50% duty
cycle, consuming at most half of the total bandwidth.

10 The term adjacent sectors as used herein means a
sector which shares a common boundary with another
sector, with the boundaries being defined in the various
embodiments of the invention as three lines comprising
one sector of a hexagon shaped cell. A point which is

15 necessarily formed from the joining of any two of the
three boundary lines is not considered a boundary for
any of the various embodiments of the invention
described herein. Similarly, although a cell is
typically represented as a hexagon to facilitate the

20 theoretical construction of a cell pattern, it can be
appreciated that the actual implementation of a cellular
system creates boundaries that do not necessarily follow
precisely the theoretical pattern. Consequently, any
reference to a common boundary refers to the boundaries

25 formed using the theoretical pattern, not the actual
implementation. The above notwithstanding, any boundary
line contemplated and used in a theoretical pattern
falls within the meaning of the term boundary as used
herein.

30 One method for improving system performance for the
time-slot assignment scheme discussed with reference to
FIG. 5 is for a sector to borrow time slots from other
subframes. This approach does not increase the overall
system capacity for uniform traffic load, but it does

35 enable efficient bandwidth sharing, especially for
transient surges of traffic load. Borrowing time slots

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from other subframes used by neighboring sectors,
however, requires a central controller or information
exchange and coordination among base stations which
significantly increases the cost and complexity of the
5 system.

A better method for improving system performance
for this assignment scheme is by allowing the use of
slots in a subframe not originally assigned to a given
sector. A left-right protocol is applied to minimize
10 concurrent transmissions, thereby reducing interference.

FIG. 6 is a diagram illustrating a left-right
protocol in accordance with a second embodiment of the
invention. A scheduler schedules when a communications
site is to transmit information in a subframe to avoid
15 major sources of interference from other communications
sites. The scheduler accomplishes this using the left-
right protocol. According to the left-right protocol,
the scheduler creates two transmission schedules. The
first transmission schedule is referred to as an
20 original transmission schedule. The second transmission
schedule is referred to as an excess transmission
schedule.

According to the original transmission schedule,
communications sites within label-1 sectors are
25 scheduled to transmit packets in time slots starting
from the left-hand side of subframe 1, or rather from t1
to t2. Communications sites within label-2 sectors,
however, are scheduled to transmit in time slots
starting from the right-hand side of subframe 2, or
30 rather from t3 to t2. Thus, it can be appreciated that
the left-right protocol alternates from which side a
communications site is to transmit information in its
assigned subframe.

It is worthy to note that the terms left side and
35 right side as used herein correspond to start times and
end times for a time subframe. The terms left side and

right side are therefore used herein to denote temporal references not spatial references.

If the information for label-1 sectors are in excess of the amount of information capable of being transmitted in subframe 1, the left-right protocol creates an excess information schedule. The left-right protocol dynamically schedules the excess information from subframe 1 for transmission in subframe 2 from the left hand side of subframe 2, that is from t2 to t3. The excess information for subframe 2 is scheduled for transmission in subframe 1 from the right hand side of subframe 1, that is from t2 to t1. Since the left-right protocol schedules the transmission of excess information in opposite directions from the original transmission schedule for a subframe, the chances for collisions are minimized.

As illustrated above, the term "excess information" is used to describe information generated from a communication site within a sector which is in excess of the amount of information that can be transmitted in the sector's originally assigned time subframe. The term excess information does not refer to information which is unnecessary or superfluous.

Depending on traffic load, the left-right protocol yields as many as 3 to 6 concurrent packet transmissions in each time slot for each cell. Ideally, all sectors in a cell can transmit simultaneously, thereby yielding a sector reuse factor of one in every sector of every cell. Of course, if concurrent packet transmissions result in unsuccessful reception, the system merely retransmits the information using any conventional retransmission scheme.

By scheduling excess information from one subframe to another subframe within the same cell, a communication site within a sector can dynamically access additional bandwidth upon demand. Since this

embodiment of the invention uses packet switching rather
than circuit switching, this embodiment does not
maintain a fixed correspondence between time slots
within a subframe and communications sites. Rather,

5   this embodiment of the invention dynamically assigns
time slots within a subframe according to the amount of
information to be transmitted by the communications
sites.

The left-right protocol takes advantage of the fact

10 that every communication site located throughout the
cell is unlikely to be operating at full capacity at the
same time. A more likely scenario is that, for example,
one terminal station is going to be accessing the
Internet to engage in video-conferencing or to watch the

15 latest news report, while another is simply reading
text-based e-mail. Thus, since terminal stations will
vary in their bandwidth need at any given moment, the
left-right protocol implements a method which takes
advantage of subframes for sectors with terminal

20 stations that are less active, utilizing a scheme which
minimizes the chances of collisions between sectors.
For example, if a base station has 10 time slots worth
of information to transmit to a terminal station, the
system dynamically allocates 10 time slots to .

25 accommodate the transmission. Similarly, if a base
station only has 2 time slots worth of information, only
2 time slots are allocated by the system. Consequently,
if a communication site or plurality of communication
sites within that sector are engaging in bandwidth

30 intensive activities to the point where all time slots
within an initial sector's subframe are used, the system
can use another sector's subframe to transmit the excess
information. The system will select another subframe
originally scheduled to fill its subframe from the

35 opposite side of the initial subframe. Thus, assuming
that the full capacity of the overflow subframe is not

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being utilized by its corresponding sector, the risk of
collisions due to interference is minimized. In the
event of collisions, the system merely retransmits the
information using any conventional retransmission
5   scheme.

        It is important to note that although the left-
right protocol was illustrated herein using a cell with
six sectors and two subframes, it can be appreciated
that any combination of sectors and subframes fall
10 within the scope of the invention.

        FIG. 7 is a cellular map with each cell divided
into six sectors and six subframes in accordance with a
third embodiment of the invention. The assignment
scheme shown in FIG. 7 is similar to the assignment
15 scheme described above with reference to FIG. 6. In
FIG. 7, however, time slots are now grouped into
subframes 1 through 6 and sectors are labeled 1 through
6 counter-clockwise. The labeling patterns for adjacent
cells differ by a 120 degree rotation. This rotation
20 creates a 3 cell pattern which can be repeated across
the entire system. It is important to note that
adjacent sectors use different subframes. Under this
embodiment, sector i can schedule packet transmission in
subframe i for $i = 1$ to 6.

25   This assignment scheme is very similar to the
assignment scheme discussed in the first embodiment of
the invention with reference to FIG. 5. Using the
assignment scheme discussed with reference to FIG. 7, it
can be appreciated that if all sectors have a traffic
30 load of less than one-sixth of the total channel
capacity, all packets are transmitted in different time
subframes, thus causing no interference within the same
cell. Similarly, because of the 120 degree rotation of
labeling patterns among adjacent cells, adjacent sectors
35 of adjacent cells also transmit in different time
subframes, thus avoiding the major sources of

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interference from the adjacent cells. Consequently, the
same frequency can be used in every sector of every
cell.

This assignment scheme represents a very
5   conservative approach since each sector can use only
one-sixth of the total bandwidth. This approach may be
appropriate for a radio environment where concurrent
packet transmissions within the same cell can cause
severe interference, or under low traffic conditions.
10   To enhance this conservative assignment scheme, a
staggered resource assignment (SRA) protocol is
introduced to permit a communication site within a cell
to dynamically access bandwidth according to its current
needs.
15   FIG. 8 is a diagram illustrating a SRA protocol in
accordance with a fourth embodiment of the invention.
This SRA protocol is illustrated herein using the
assignment scheme discussed with reference to FIG. 7.

The SRA protocol maximizes concurrent packet
20   transmissions while minimizing packet collisions
utilizing the spirit of the left-right protocol concept.
As with the embodiment discussed with reference to FIG.
6, a scheduler creates an original transmission schedule
and an excess transmission schedule. The excess
25   transmission schedule is generated in accordance with
the SRA protocol.

According to the original transmission schedule for
this embodiment, communications sites within each sector
are to schedule transmissions in each sector's
30   originally assigned subframe from the left hand side.

In the excess information transmission schedule,
excess information for a sector, referred to as an
initial sector, is scheduled for transmission in
subframes originally assigned to other sectors within
35   the same cell. When subframes originally assigned to
other sectors within the same cell are used to transmit

excess information, these subframes are referred to as excess information subframes.

The scheduler selects excess information subframes according to a special order. The special order takes advantage of the directional antennas used within the system to minimize the amount of interference arising from concurrent packet transmissions. Concurrent packet transmissions refers to the use of a single time slot to transmit information from communications sites located in more than one sector.

The SRA protocol generates the special order by ordering the excess information subframes from those subframes originally assigned to sectors producing the least amount of interference for the communication site generating the excess information (MIN interference), to those subframes originally assigned to sectors producing the greatest amount of interference (MAX interference). Thus, if interference due to concurrent packet transmission in the same cell can be tolerated, a sector should use the first subframe of the opposite sector in the same cell after using all slots in the initial subframe, thereby making the best use of the base station directional antennas. Following that, time slots in the subframes for the sectors next to the opposite sector are used. To avoid interference due to imperfect antenna patterns of neighboring sectors, subframes for sectors adjacent to the initial sector are used as a last resort.

As shown in FIG. 8, for example, the special order for sector 1 is subframe 1 (a), subframe 4 (b), subframe 5 (c), subframe 3 (d), subframe 2 (e) and subframe 6 (f). Thus, the scheduler first schedules information for transmission by a communications site in a label-1 sector in time slots of subframe 1 (denoted by a). If the sector has more traffic to send, it uses subframe 4, subframe 5, and so forth, until subframe 6.

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As also shown in FIG. 8, the assignment order for the next sector is "staggered" by a right rotation by one subframe based on the order for the previous sector. Thus for sector 2, the sequential order for excess

5 information schedule is subframes 5 (b), 6 (c), 4 (d), 3 (e) and 1 (f). Hence, this method is referred to as a "staggered" resource allocation method.

In addition to the excess information schedule indicating the order of excess information subframes to

10 be used, the excess information schedule also indicates from which side transmission of excess information is to be scheduled in the excess information subframes. To accomplish this, the scheduler uses the spirit of the left-right protocol. More specifically, the scheduler

15 alternates scheduling packet transmissions for each subframe from each subframes' left side or right side starting with the initial subframe and following with the other subframes according to the special order.

For example, assume subframe 1 is the initial

20 subframe for sector 1. Information from sector 1 is scheduled to transmit information in subframe 1 (a) from the left hand side. Following the special order for the excess information schedule for sector 1, excess information is scheduled to be transmitted in subframe 4

25 (b) from the right hand side, followed by subframe 5 (c) from the left hand side, subframe 3 (d) from the right hand side, subframe 2 (e) from the left hand side, and finally subframe 6 (f) from the right hand side. The purpose for alternating sides is to further avoid

30 collisions due to concurrent packet transmissions, thus reducing interference and enhancing system throughput. This is especially true in a case where there is uniform traffic load among sectors.

To better illustrate this concept, consider

35 subframe 1 shown in FIG. 8. According to the SRA protocol, sector 4 uses subframe 1 as the second

subframe (denoted by *b*) for transmission. To avoid
concurrent transmission with sector 1, which starts from
the left-hand side of subframe 1, sector 4 schedules
packet transmission from the right-hand side. In many
5   instances, sector 4 will not have enough packets to send
in all slots of subframe 1, thus avoiding concurrent
transmission with sector 1 as much as possible.

        The fact that sector 3 needs to transmit in
subframe 1 *(c)* in the SRA order implies that sector 1
10   will have a similar traffic load under uniform traffic
conditions. Thus, it is likely that sector 1 will
transmit in all slots in subframe 1. Consequently, the
scheduling direction for sector 3 (from the left or the
right-hand side) is unlikely to help avoid interference
15   from transmission of sector 1.

        By way of contrast, it is probable that sector 4
may not need to transmit in all slots in subframe 1
(which is the second subframe for sector 4). Under the
same rationale applied for the opposite scheduling
20   directions for sectors 1 and 4, since sector 4 schedules
from the right-hand side, sector 3 should begin
transmission from the left-hand side of subframe 1 to
avoid possible interference between sectors 3 and 4.
The same rationale applies to the scheduling directions
25   of other sectors and other time subframes.

        As for avoiding interference, it can be seen from
FIG. 8 that if all sectors have a traffic load of less
than one-sixth of the total channel capacity, all
packets of different sectors are transmitted in
30   different time subframes, thus causing no interference
within the same cell. Of course, packets are
transmitted simultaneously as the traffic load
increases, thus increasing the level of interference.
Nevertheless, the SRA protocol takes advantage of the
35   characteristics of directional antennas to allow
multiple concurrent packet transmissions while

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maximizing the SIR.

For a given radio environment and antenna characteristics, network operators can choose a parameter to control (limit) the number of concurrent
5   transmissions by not scheduling transmission beyond the first few subframes. For example, if at most three packets can be sent simultaneously by various base station or terminal station antennas in the same cell, only time slots in subframes *a*, *b* and *c* would be used
10 for transmission by each antenna.

In addition to managing intra-cell interference, the SRA protocol helps avoid interference from major sources in the neighboring cells. This is particularly true when traffic load is low to moderate. To better
15 illustrate this, consider the downlink for Sector 1 in the middle cell of FIG. 7. Sector 2 in the bottom cell and Sector 3 in the upper cell are the major sources of interference. By examining the assignment order for sectors 1, 2 and 3 in accordance with the SRA protocol
20 in FIG. 8, it can be appreciated that these sectors will not transmit simultaneously, thus not interfering with each other provided that they have a traffic load of less than one-third of total channel capacity, i.e., using only subframes *a* and *b* for transmission.
25 Similarly, the uplink for sector 1 in the middle cell of FIG. 7 will not transmit simultaneously with sectors 2 and 5 of the bottom cell, which now become the major sources of interference. Due to the symmetry of the assignment order and cell layout, the SRA protocol, as
30 well as the other embodiments of the invention, avoids the major interference for each sector in every cell.

The SRA protocol is variable depending on traffic load and a control parameter, with the number of concurrent packet transmissions in each cell ranging
35 from 1 to 6. The control parameter can be chosen depending on the SIR and other requirements. As with

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previous embodiments of the invention, the SRA protocol can work with any number of sectors or cells.

FIG. 9 is a normalized throughput v. normalized aggregated load graph in accordance with the fourth

5 embodiment of the invention. An approximate analytic model has been developed to study the throughput characteristics of the SRA protocol. The model considers a fixed number of terminals (e.g., homes) randomly placed throughout each sector, finite FTB

10 ratios for base station and terminal station antennas, radio path loss and lognormal shadowing effects.

FIG. 9 displays a sample of the numerical results for this analytic model. In this model, each subframe has 2 time slots, each sector has 20 terminals, the

15 standard deviation of lognormal shadowing is 4 decibels (dB) and the path loss exponent is 4. FIG. 9 presents the downlink throughput of the SRA protocol for a set of typical FTB ratios for base station and terminal station antennas, denoted by B and T, respectively, in the

20 figure. The throughput depends on the SIR detection threshold (Th). Using straightforward modulation and equalization schemes, e.g., Quadrature Phase Shift Keying (QPSK) and Decision Feedback Equalizers (DFE), the threshold typically lies somewhere between 10 to 15

25 dB. As shown in FIG. 9, the maximum throughput in each sector for the SRA protocol with these parameters ranges from 30% to 75%. That is, while re-using the same frequency to support high user data rates in every sector of every cell, this embodiment of the invention

30 can achieve a throughput in excess of 30%. This throughput rate translates into a very large network capacity. This is because the SRA protocol is capable of selectively allowing concurrent packet transmission to increase throughput while avoiding major interference

35 to yield satisfactory reception.

Although various embodiments are specifically

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illustrated and described herein, it will be appreciated
that modifications and variations of the present
invention are covered by the above teachings and within
the purview of the appended claims without departing

5   from the spirit and intended scope of the invention.
For example, although a TDMA system was used to
illustrate various embodiments of the invention, it can
be appreciated that any time based system falls within
the scope of the invention. Similarly, although various

10   embodiments of the invention make reference to fixed
terminal stations, it can be appreciated that mobile
terminal stations fall within the scope of the
invention. Another example includes the number of
sectors and cells discussed in the various embodiments.

15   It can be appreciated that any number of sectors or
cells falls within the scope of the invention.

25

What is claimed is:

1 1.   A method for scheduling transmissions between a
2 plurality of communications sites within a
3 communications system, the communications system having
4 a service area divided into a plurality of sectors, with
5 each sector assigned a time subframe in a pattern where
6 adjacent sectors use different subframes, comprising the
7 steps of:
8   scheduling packet communications for communications
9 sites located within each sector, wherein each
10 communication site is scheduled to communicate said
11 packets in at least one time subframe to avoid
12 interference from other sectors; and
13   communicating said packets according to said
14 scheduling.

1 2.   The method described in claim 1, wherein said
2 scheduling step creates an excess information
3 transmission schedule.

1 3.   The method described in claim 2, wherein said
2 excess information transmission schedule indicates when
3 excess information for an initial subframe is to be
4 transmitted in other subframes.

1 4.   The method described in claim 3, wherein said other
2 subframes are selected according to a special order.

1 5.   The method described in claim 4, wherein said
2 special order is created by ordering all subframes from
3 MIN interference to MAX interference.

1 6.   The method described in claim 5, wherein said
2 special order is created using a staggered resource
3 allocation protocol.

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1 7.   The method described in claim 6, wherein each
2 subframe has a left side and right side, and said
3 scheduling step schedules when each communication site
4 is to transmit information in each subframe from each
5 subframes' left side and right side.

1 8.   The method described in claim 7, wherein said
2 scheduling step alternates between scheduling
3 transmissions for each subframe from each subframes'
4 left side and right side starting with said initial
5 subframe and following with said other subframes
6 according to said special order.

1 9.   The method described in claim 8, wherein the
2 service area has a plurality of cells, and each cell has
3 six sectors.

1 10.   The method described in claim 9, wherein the system
2 has six subframes, with each sector within a cell using
3 a different subframe.

1 11.   The method described in claim 10, wherein the
2 pattern is created by rotating each cell 120 degrees.

1 12.   The method described in claim 11, wherein said
2 initial subframe for sector one is subframe one, and
3 said special order comprises subframes four, five,
4 three, two and six.

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1   13.   The method described in claim 12, where when said
2   initial subframe is subframes two through six, said
3   staggered resource allocation protocol staggers said
4   special order by one subframe, respectively.

1   14.   The method described in claim 13, wherein each
2   subframe has a left side and right side, and said
3   scheduling step creates an original transmission
4   schedule by scheduling when each communication site is
5   to transmit information from a subframe's left side and
6   right side.

1   15.   The method described in claim 14, wherein said
2   scheduling step schedules said excess information in a
3   first of said other subframes from a direction opposite
4   of which said first of other subframes was originally
5   scheduled to transmit in said original transmission
6   schedule.

1   16.   The method described in claim 1, wherein the system
2   has a first and second subframe, and each pair of
3   sectors within a cell has a first and second sector,
4   wherein communications sites within said first sector
5   transmit packets in said first subframe, and
6   communications sites within said second sector transmit
7   packets in said second subframe.

1   17.   A method for reusing a common frequency in each
2   sector of a communications system, comprising the steps
3   of:
4   identifying major sources of interference for
5   communications sites located within each sector; and
6   scheduling packet transmissions in all sectors to
7   avoid said interference.

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1 18.   The method described in claim 17, wherein said
2 scheduling step schedules packet transmissions to
3 maximize concurrent packet transmissions within a cell.

1 19.   A communications system having a plurality of
2 communications sites, the system having a service area
3 divided into a plurality of sectors with a time subframe
4 assigned to each sector in a pattern where adjacent
5 sectors use a different subframe, comprising:
6   a plurality of communications units operably
7 associated with the service area for communicating
8 between the communications sites using at least one time
9 subframe;
10   a scheduler for scheduling information for
11 communicating in each subframe.

1 20.   The system described in claim 19, wherein said
2 scheduler creates an excess information transmission
3 schedule.

1 21.   The system described in claim 20, wherein said
2 excess information transmission schedule indicates when
3 excess information for an initial subframe is to be
4 transmitted in other subframes.

1 22.   The system described in claim 21, wherein said
2 other subframes are selected according to a special
3 order.

1 23.   The system described in claim 22, wherein said
2 special order is created by ordering all subframes from
3 MIN interference to MAX interference.

1 24.   The system described in claim 23, wherein said
2 special order is created using a staggered resource
3 allocation protocol.

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1   25.   The system described in claim 24, wherein each
2   subframe has a left side and right side, and said
3   scheduler schedules when each communication site is to
4   transmit information in each subframe from each
5   subframes' left side and right side.

1   26.   The system described in claim 25, wherein said
2   scheduler alternates between scheduling transmissions
3   for each subframe from each subframes' left side and
4   right side starting with said initial subframe and
5   following with said other subframes according to said
6   special order.

1   27.   The system described in claim 26, wherein the
2   service area has a plurality of cells, and each cell has
3   six sectors.

1   28.   The system described in claim 27, wherein the
2   system has six subframes, with each sector within a cell
3   using a different subframe.

1   29.   The system described in claim 28, wherein the
2   pattern is created by rotating each cell 120 degrees.

1   30.   The system described in claim 29, wherein said
2   initial subframe for sector one is subframe one, and
3   said special order comprises subframes four, five,
4   three, two and six.

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1   31.   The system described in claim 30, where when said
2   initial subframe is subframes two through six, said
3   staggered resource allocation protocol staggers said
4   special order by one subframe, respectively.

1   32.   The system described in claim 21, wherein each
2   subframe has a left side and right side, and said
3   scheduler creates an original transmission schedule by
4   scheduling when each communication site is to transmit
5   information from a subframe's left side and right side.

1   33.   The system described in claim 32, wherein said
2   scheduler schedules said excess information in a first
3   of said other subframes from a direction opposite of
4   which said first of other subframes was originally
5   scheduled to transmit in said original transmission
6   schedule.

1   34.   The system described in claim 19, wherein the
2   system has a first and second subframe, and each pair of
3   sectors within a cell has a first and second sector,
4   wherein communications sites within said first sector
5   transmit packets in said first subframe, and
6   communications sites within said second sector transmit
7   packets in said second subframe.

FIG. 1

FIG. 2A

$K=4$

$K=7$

FIG. 2B

$K=12$

FIG. 2C

FIG. 2D

$K = i^2 + ij + j^2 = 19$

FIG. 3

FIG. 4

●   ●

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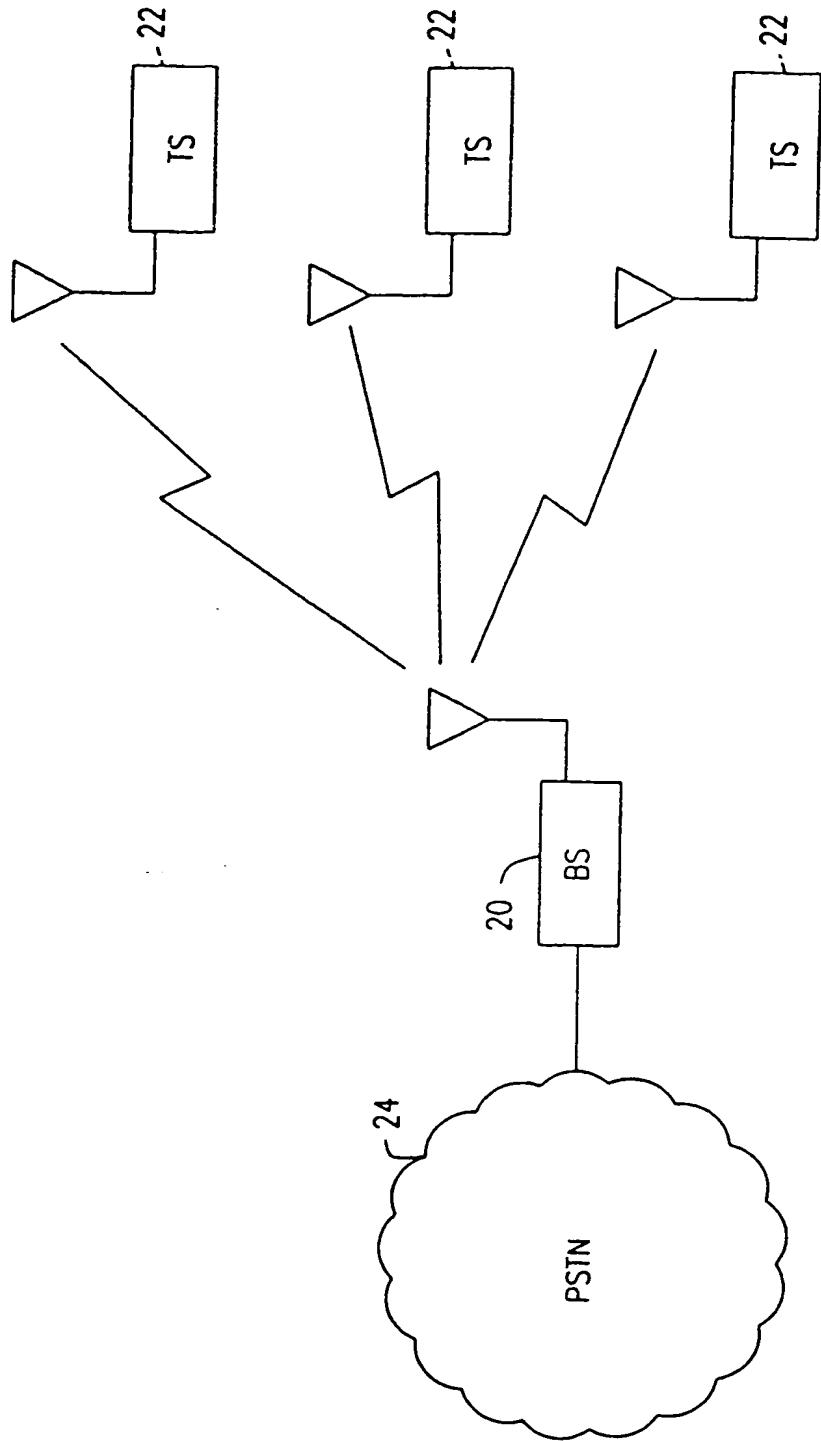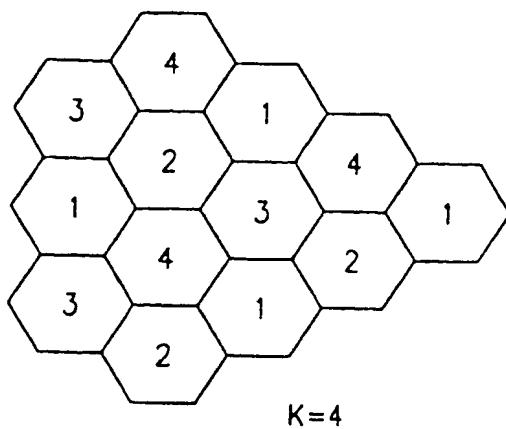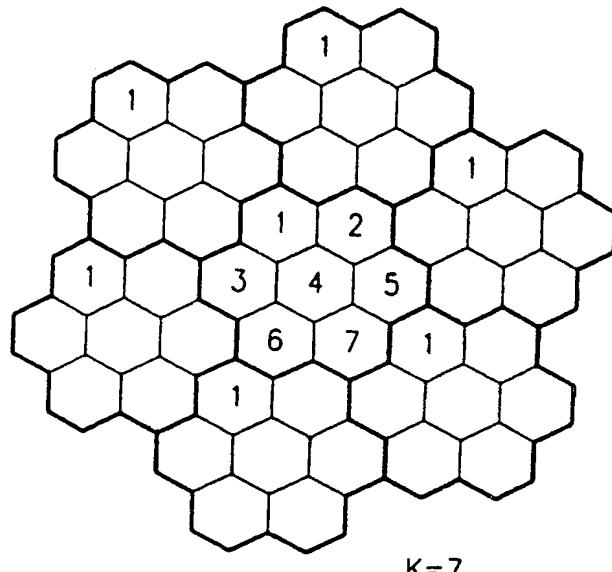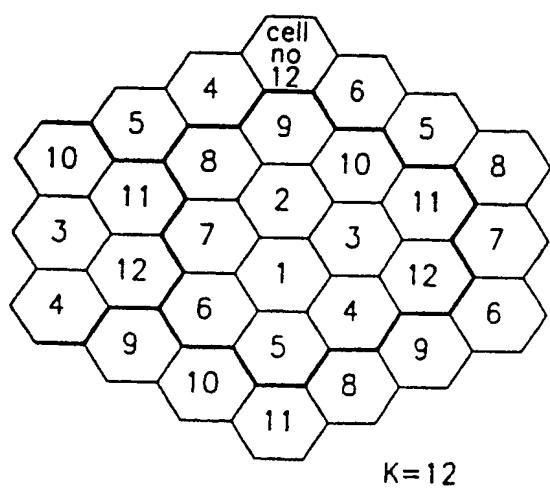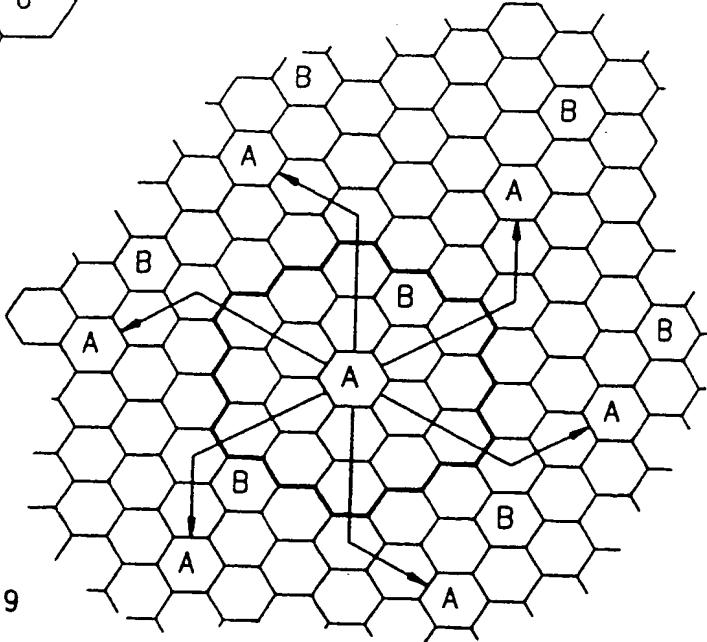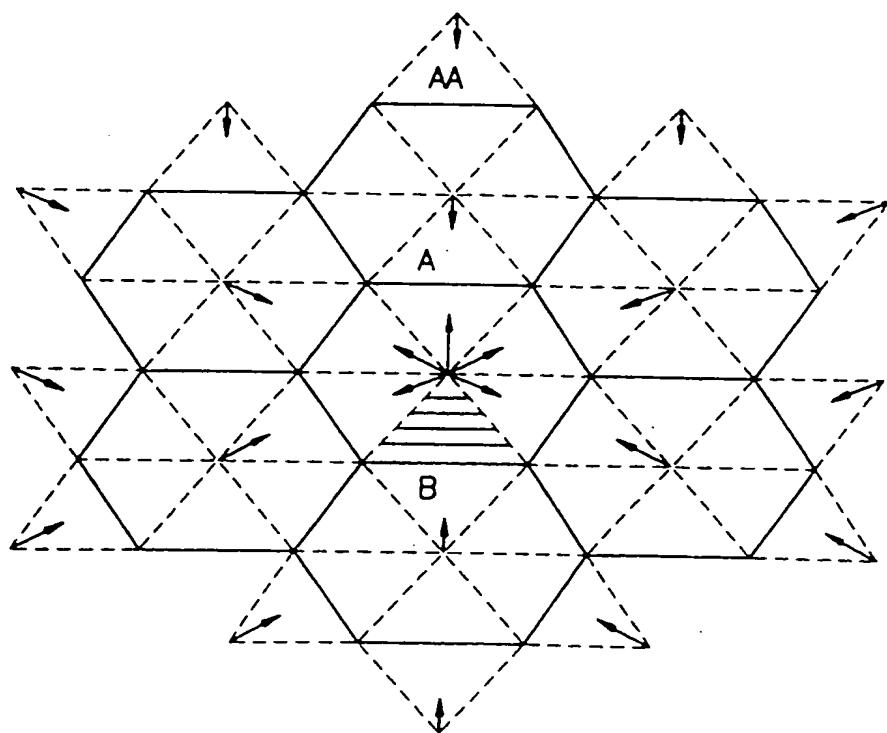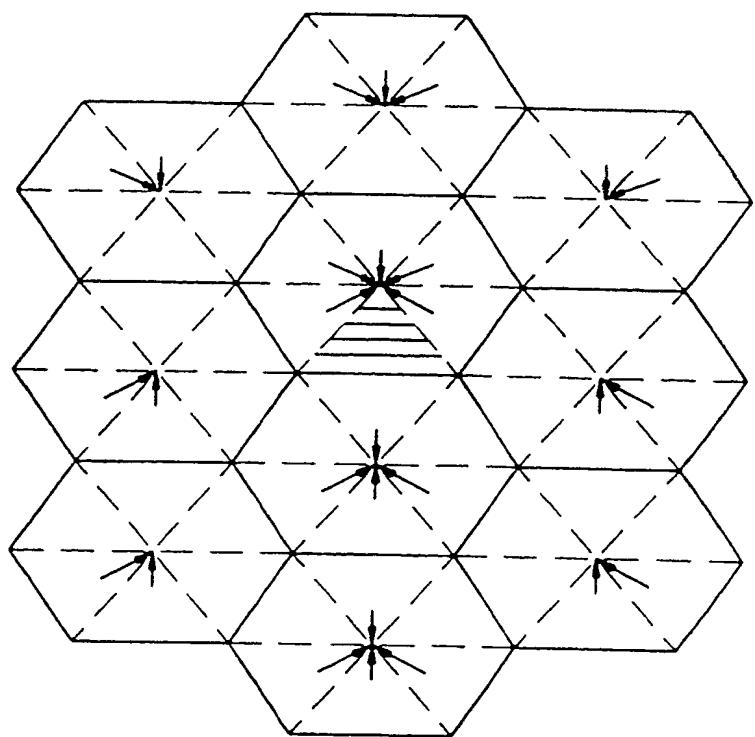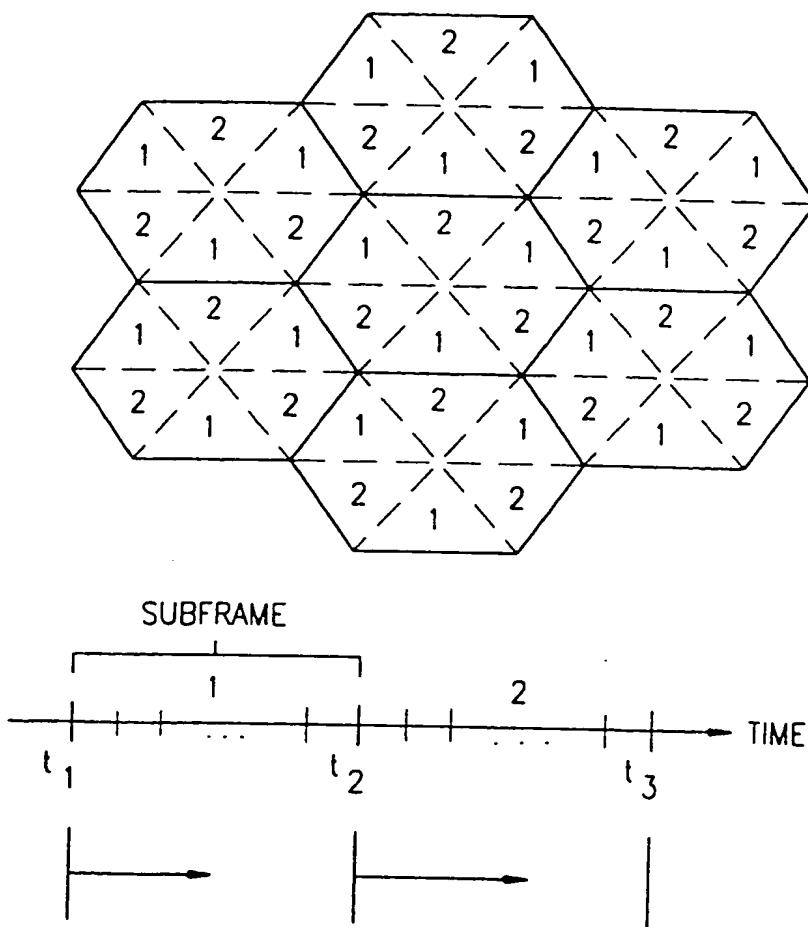
FIG. 5
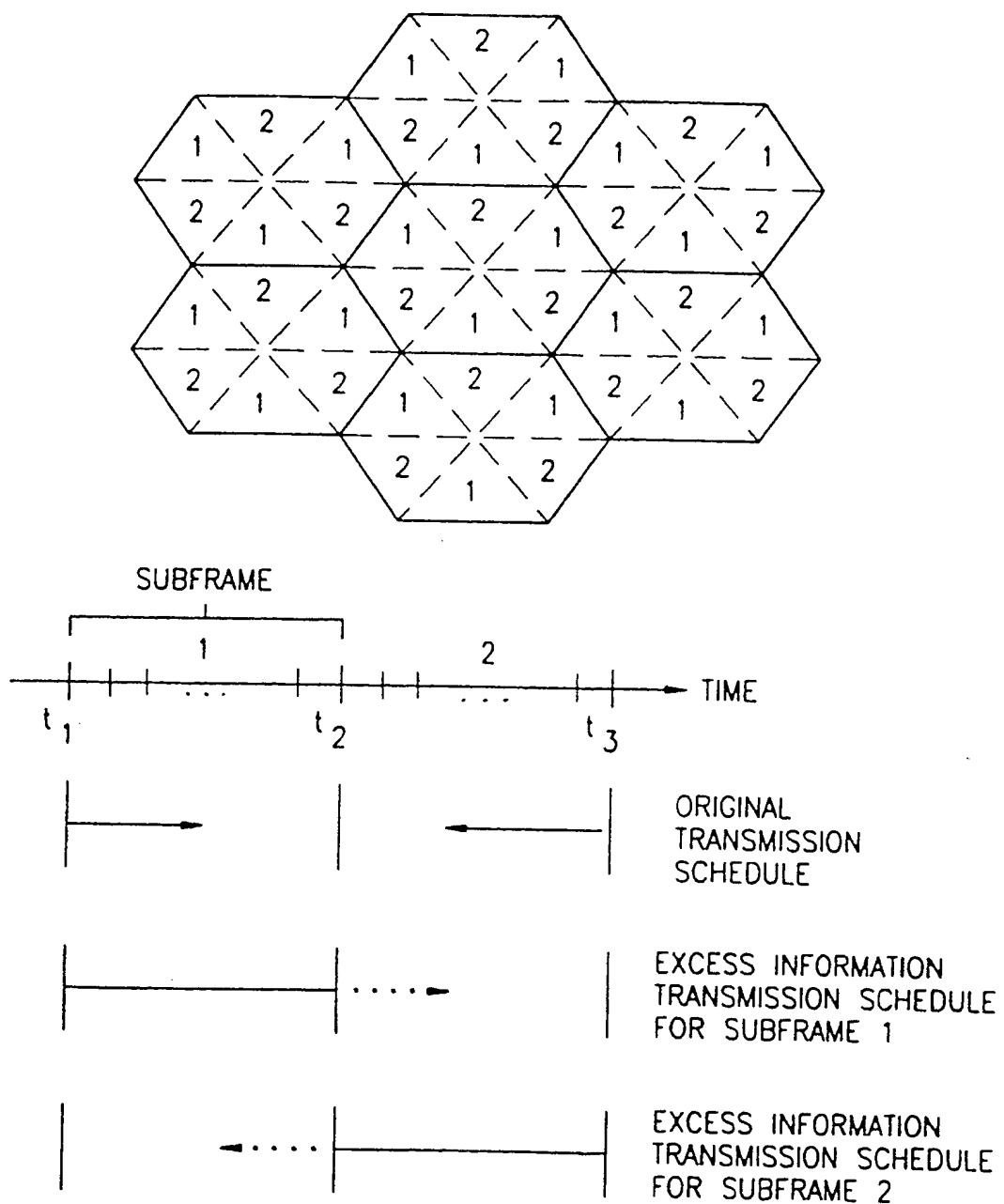
FIG. 6
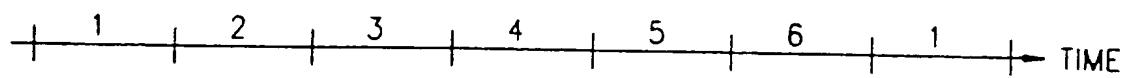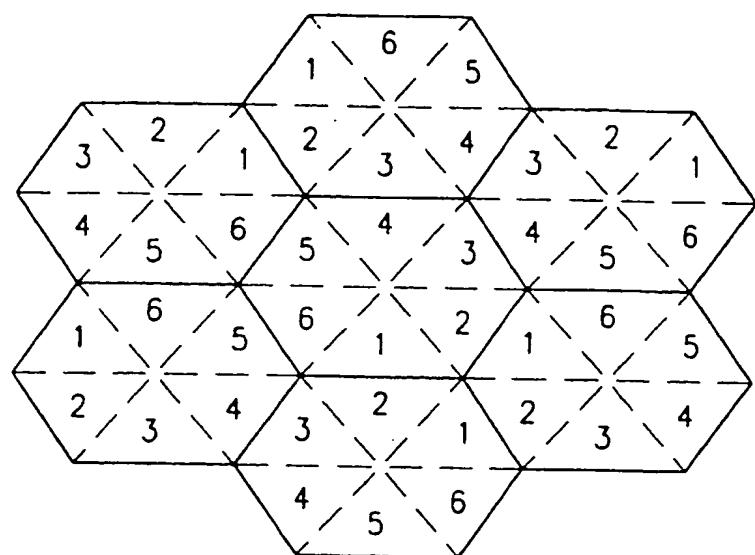
FIG. 7
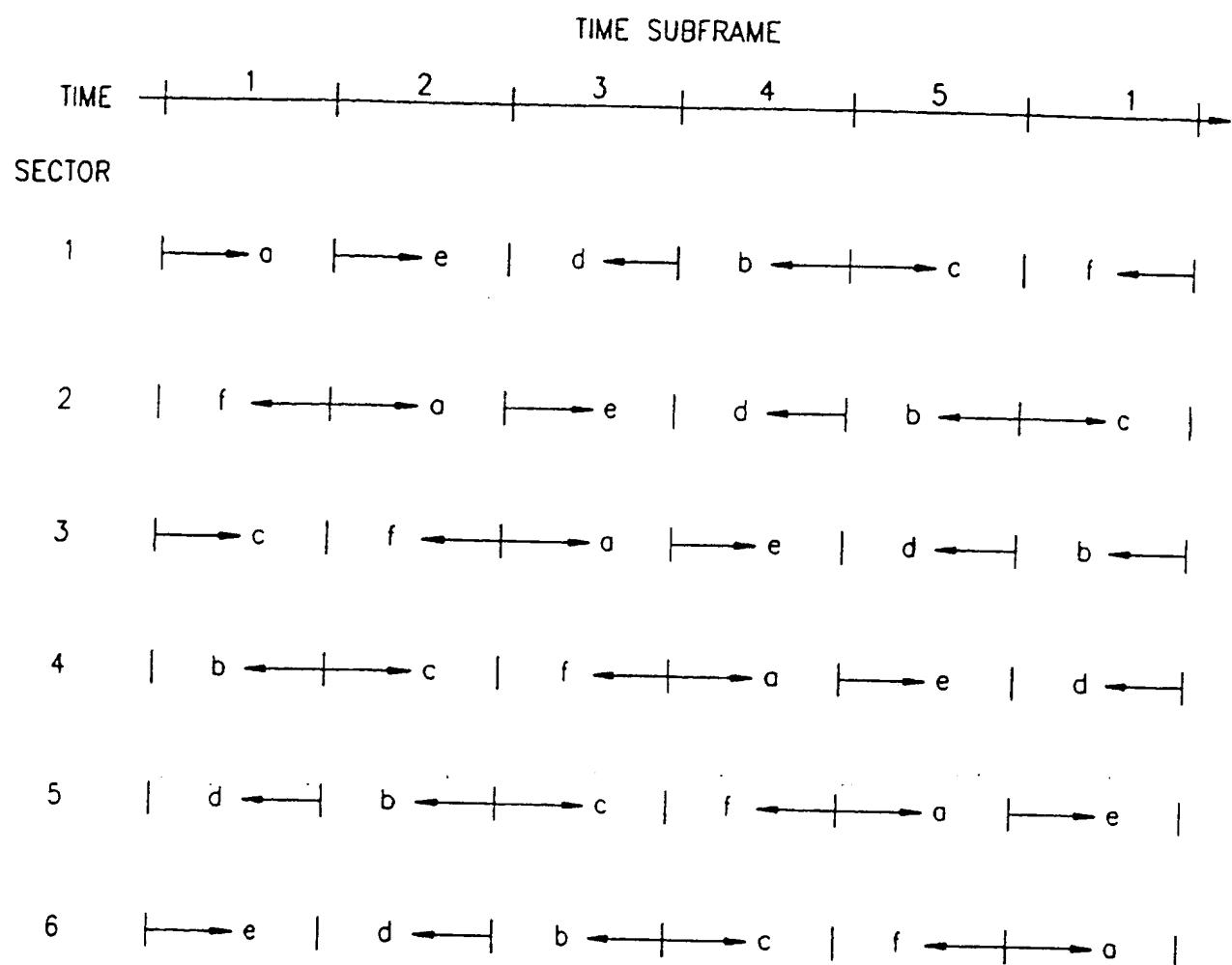
FIG. 8

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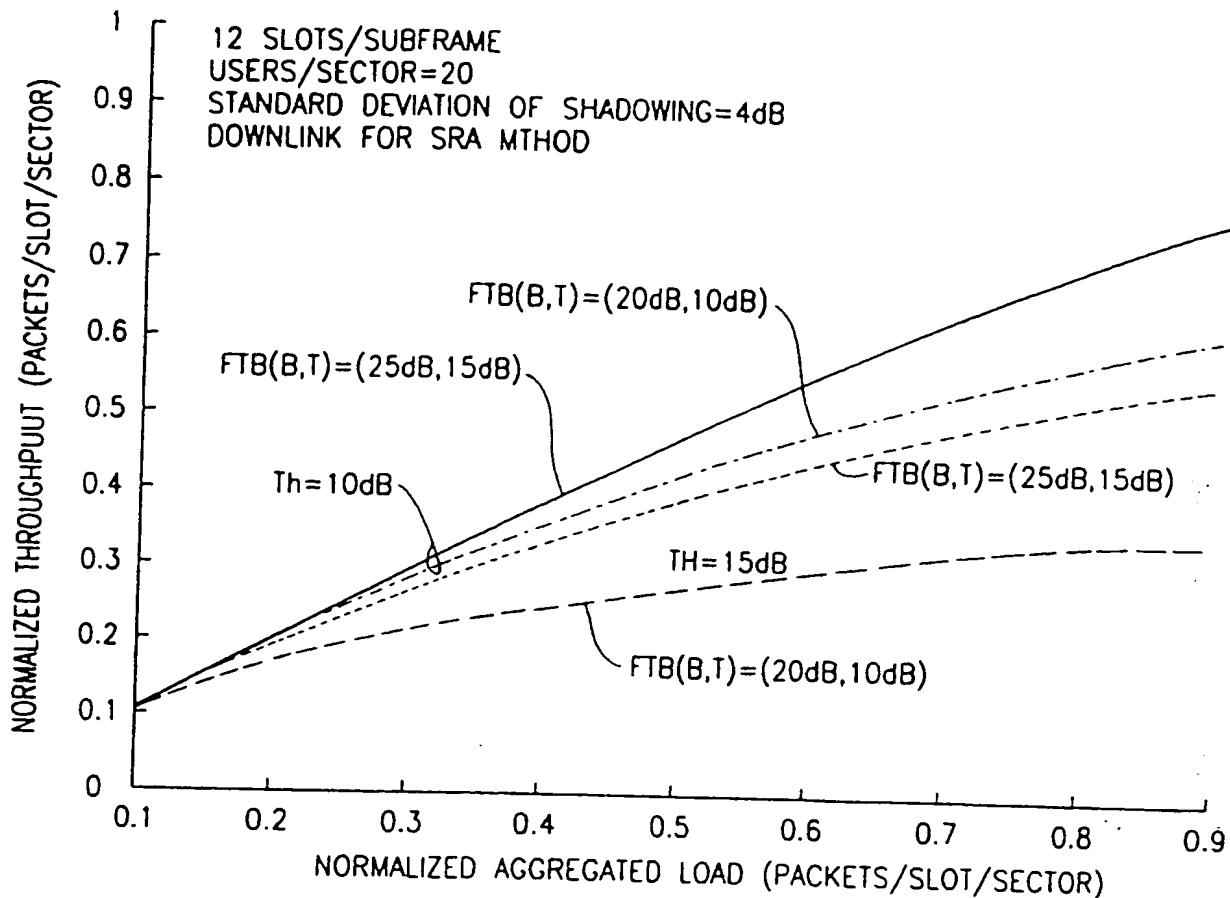
FIG. 9

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   H04L12/56   H04Q7/36

According to International Patent Classification(IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   H04L   H04Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 150 399 A (LICENTIA GMBH) 7 August 1985 see abstract see page 1, line 4 – page 3, line 24 see figures 1,2	1,16-19, 34
Y		2-4, 20-22
A		5,9-12, 23,27-30

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[X] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

° Special categories of cited documents :

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 April 1998	21/04/1998

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Vaskimo, K

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INTERNATIONAL SEARCH REPORT

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication.where appropriate. of the relevant passages	Relevant to claim No.
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